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10R RANDOM VIBRATION TESTS OF CASSINI SPACECRAFT EQUIPMENT

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ABSTRACT

During the past two years, force limiting has been used in the random vibration tests of many of the equipment items on the Cassini spacecraft. (See for' example "Force Limited Vibration Testing of Cassini Spacecraft Cosmic Dust Analyzer" [Jahn 96].) The force limits for the CDA and other equipment on the Cassini spacecraft were derived using the methods described in the 1994 Spacecraft Structures and Mechanical Testing Conference, [Scharton 94]. Herein, verification of the Cassini equipment random vibration test acceleration and force specifications is provided by interface acceleration and force data measured in acoustic tests of the Cassini spacecraft development test model (DTM).

Three acoustic tests have been performed on the Cassini DTM structure with different structural and equipment configurations. The acceleration and force spectra at the interfaces between tile equipment items and the spacecraft DTM structure were measured in the acoustic tests and compared with the equipment random vibration test specifications. The spacecraft apparent masses were also measured at the equipment mounting points on the DTM structure and used in the force limit prediction methods. The prc.dieted force. limits are shown to be very conservative with respect to (much gr'cater. than) the measured limits. The force prediction methods have been verified but they need to be refined and validated with more system and flight data. The acoustic test data showed that the equipment random vibration test acceleration specifications were also conservative, but not unduly so.

1. DESCRIPTION OF CASSINI MISSION

Saturn and its moon Titan wili be the destination for the Cassini mission, a project under joint development by NASA, tile European Space Agency (ESA) and the Italian Space Agency. The U.S. portion of the mission is managed for NASA by the Jet Propulsion Laboratory (JPL). After arriving, at the ringed planet, the Cassini orbiter (see Fig. 1) will release the Huygens probe, provided by ESA, which will descend to the surface of Titan. The Cassini orbiter will then continue on a mission of at least four years in orbit around Saturn. Launched in October 1997 on a Titan IV-Centaur rocket from Cape Canaveral in Florida, Cassini will first execute two gravity-assist flybys of Venus, then one each of the Earth and Jupiter to send it on to arrive at Saturn in June 2004.

The Cassini orbiter weighs a total of 2,150 kilograms (4,750 pounds); after attaching the 350-kilogram Huygens probe anti a launch vehicle adapter and loading more than 3,000 kilograms (6,600 pounds) of propellants, the spacecraft weight at launch is about 5,800 kilograms (12,800" pounds). Because of the very dim sunlight al Saturn's orbit, solar arrays are not feasible and power will bc supplied by a Set of Radioisotope Thermoelectric Generators (RTG's) which use heat from the natural decay of plutonium to generate electricity to run Cassini. Equipment for a total of twelve science experiments is carried onboard the Cassini orbiter and another six fly 011 the Huygens Titan probe.

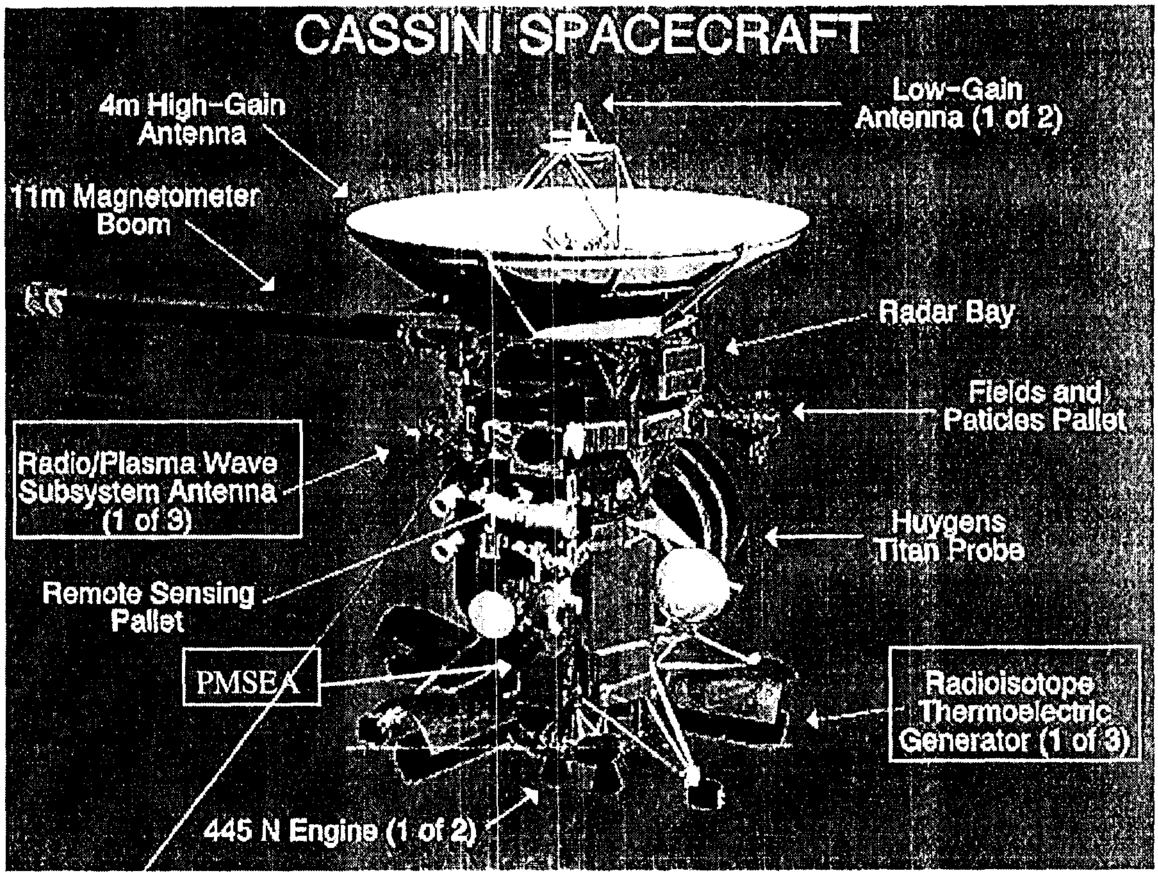


Fig. 1 Cassini Spacecraft Image (Showing Subject RTG's, RPWS, and PMSEA Equipment)

2. SPACECRAFT DTM ACOUSTIC TESTS

Three acoustic tests of the Cassini spacecraft Development Test Model (DTM) have been conducted (Aug. 94, Sept. 95, and Dec. 95) in JPL's 300" cu. m (10,000 cu. ft) reveberent acoustic chamber. Each test involved different configurations of DTM, flight, and engineering model spacecraft hardware and science instruments. The two primary objectives of these tests were: 1. To serve as precursors to the flight spacecraft acoustic test in the Fall of 1996 and 2. To provide verification of the apriori predicted acoustically-induced random vibration test levels at equipment locations on the spacecraft. The locations included the attachment interfaces of science instruments, RTG's, reaction wheels, and other spacecraft assemblies. In many cases, both the interface acceleration and interface force were measured, and in some cases the acceleration response at a position near the equipment center of gravity (c.g.) was also measured.

The Sept. 95 Cassini DTM acoustic test included the most complete spacecraft configuration, which is shown in Fig. 2. That test configuration included two mass mock-ups and one dynamic model of an RTG and an engineering model of a Radio Plasma Wave Subsystem Antenna Assembly (RPWS), which are two of the three assemblies discussed in detail herein. The third assembly discussed here is the Propulsion Module Subsystem Electronic Assembly (PMSEA) which was simulated with a mass mock-up in the Sept. '95 test, but was represented with an engineering model in the Dec. '95 follow-on DTM acoustic test.

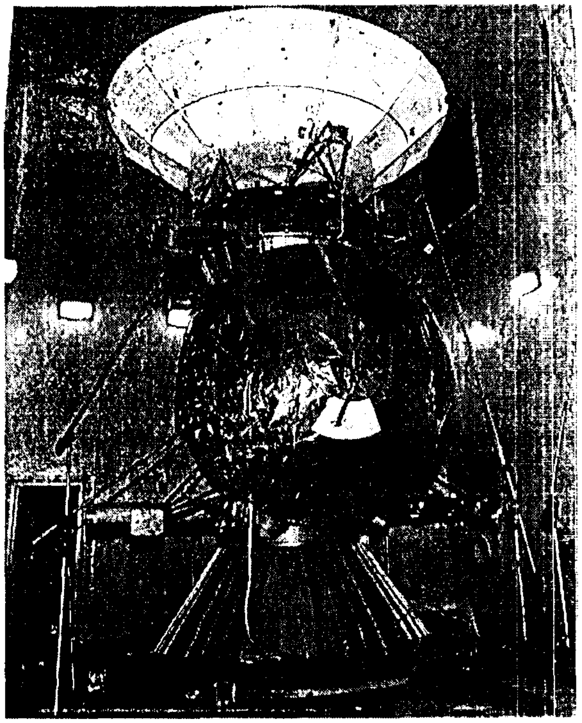


Fig. 2 DTM Spacecraft in Acoustic Chamber

3. EQUIPMENT RANDOM VIBRATION TEST SPECIFICATIONS

Acceleration Specifications

The random vibration test acceleration specifications for equipment on the Cassini space.craft were generated by dividing the spacecraft into four different zones which primarily reflected the surface density of the equipment mounting structure and the distance from acoustically responsive structures such as the high-gain antenna launch vehicle adapter, etc. The accelerations for each zone were initially determined by scaling random vibration data from JPL's Galileo spacecraft DTM and flight spacecraft acoustic tests. In special cases, e.g. the RTG's, the accelerations were determined using the VAPEPS vibroacoustic program.

As the Cassini program progressed and results from the DTM acoustic tests became available, the acceleration specifications were reviewed for each equipment item and, in general, were supported by the data. A comprehensive test program was conducted to develop an optimum acoustic liner for the. interior or the Titan/Centaur fairing. A full scale acoustic test of the fairing and spacecraft follow-on DTM confirmed the reduction of interior sound levels, so the Cassini equipment random vibration acceleration specifications were reduced by 2 dB.

Force Specifications

The Cassini spacecraft program utilizes dual control of acceleration and force in equipment random vibration tests, in order to mitigate the artificial resonances and high responses which occur in conventional vibration tests. The force limiting approach was described at the 1994 Spacecraft Structures and Mechanical Testing Conference [Scharton 94] and is also described at this conference [Jahn 96] in a companion paper dealing with the Cassini Cosmic Dust Analyzer (CDA) science instrument.

The random vibration test force specifications for most equipment on the Cassini spacecraft were generated using the Two-Degree-of-Freedom System (TDFS) models, described previously [Scharton 95]. In this approach, the equipment and mounting structure interface acceleration and force frequency spectra are calculated using the TDFS models, defined with the equipment and mounting structure modal effective masses. (Coupled system models with more than two degrees of freedom can also be used.) The calculated acceleration and force spectra are enveloped, and the ratio of force to acceleration envelopes is calculated. Finally, the force specification is generated by multiplying this ratio of envelopes by the acceleration specification. Notice that the force specifications developed in this way are proportional to the acceleration specification, so any errors, conservatism, and margin in the acceleration specification are carried over into the force specification.

Typically, the modal effective masses used to develop the force specifications were first estimated using infinite system calculations, later calculated from FEM'S [Wada 72.], and finally updated with apparent mass measurements. For the equipment, the apparent masses were measured in low level sine tests conducted as a precursor to the vibration qualification tests. For the mounting structure, the apparent masses were measured in tap tests, using a typical modal test set-up.

This paper focuses on random vibration testing, but force limiting is also used at JPL in low-frequency sine tests of equipment in the following manner. The design load is often defined as the quasi-static limit load, which may be interpreted as the acceleration of the center-of-gravity (c.g.) of the equipment. However, it is impossible to measure the acceleration of the c.g. of a nonrigid body with an accelerometer, because with deformation the c.g. becomes a virtual, not a real point. Measuring and controlling the interface force is a convenient, alternative method of limiting to the quasi-static design loads, since the external force divided by the total mass is always equal to the c.g. acceleration (Newton's 2nd Law).

4. RADIOISOTOPE THERMOELECTRIC GENERATORS (RTG's)

Figure 3 shows the dynamic model of a Cassini RTG mounted on a shaker for the axial vibration test. Four medium sized triaxial force gages are mounted between the circular shaker adapter plate and the square RTG base.

Figure 4 shows the acceleration data measured in different axes at the RTG base during the Sept. 95 DTM acoustic test. Also shown in Fig. 4 is the RTG random vibration test acceleration specification ($0.08\ G^2/Hz$), which corresponds to Cassini equipment zone 1. (In this and the similar plots presented herein, both the acoustic test data and the random vibration test specification have 4 dB of margin over the predicted flight environment.) Comparison of the data and specification in Fig. 4 indicates remarkable agreement; that is, the specification just barely envelopes the data over the complete frequency range from 20 to 1000 Hz.

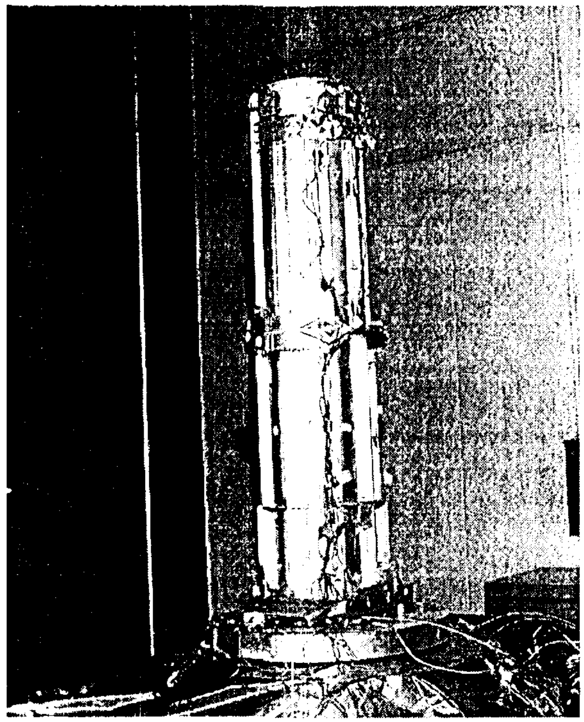


Fig. 3 Dynamic Model of Cassini RTG Mounted for Axial Vibration Test

Figure 5 shows the force data measured in different axes at the RTG base during the Sept. 95 DTM acoustic test. In each case, the force shown is the total force acting in each direction, i.e. the sum of the forces at the four RTG attachment bolts. (The real-time sum of the forces from several piezoelectric force gages is easily obtained by combining the signals from the individual gages in a junction box before the charge amplifier.) For comparison, Fig. 5 also shows the force specification for the RTG random vibration tests, derived from the TDFS as previously described. A Cassini equipment generic preliminary force specification, which is proportional to the equipment weight squared and the acceleration specification power spectral density is also shown in Fig. 5. The RTG force specification exactly envelopes the axial data at 220 Hz, which is a critical frequency for the RTG, and is quite conservative at other frequencies. The Cassini generic force specification is approximately 7 dB above the RTG force specification in the mid-frequencies.

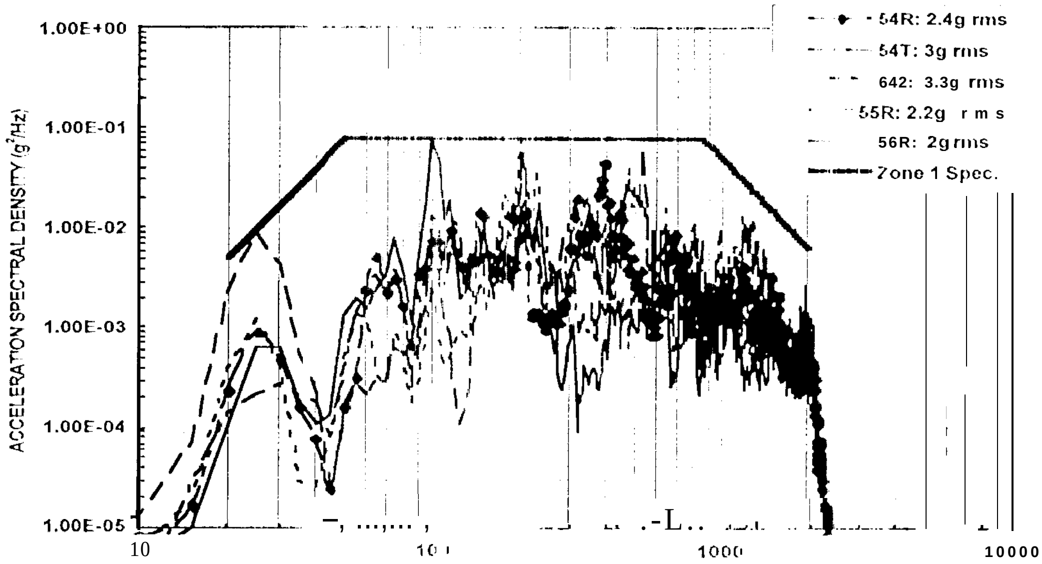


Fig. 4 Cassini RTG Base Acceleration Data and Random Vibration Specification

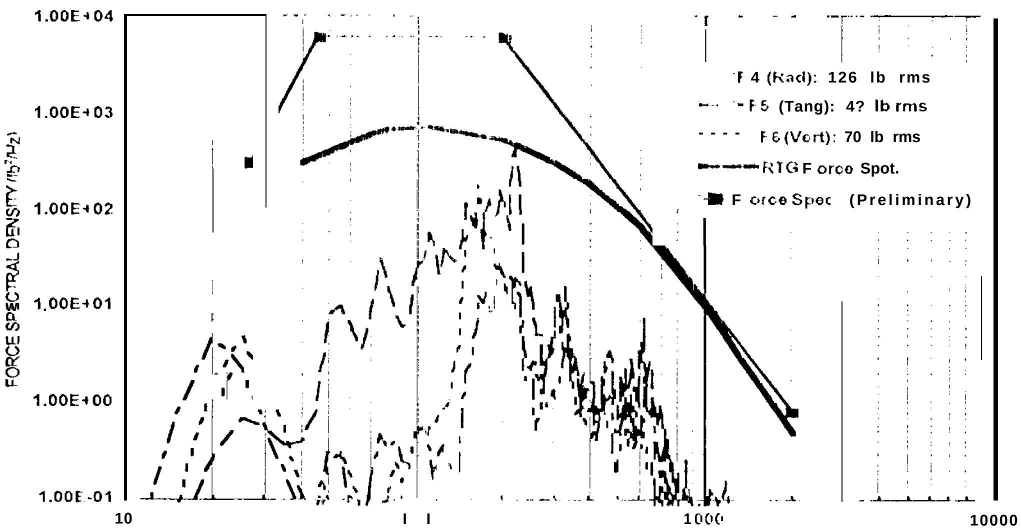
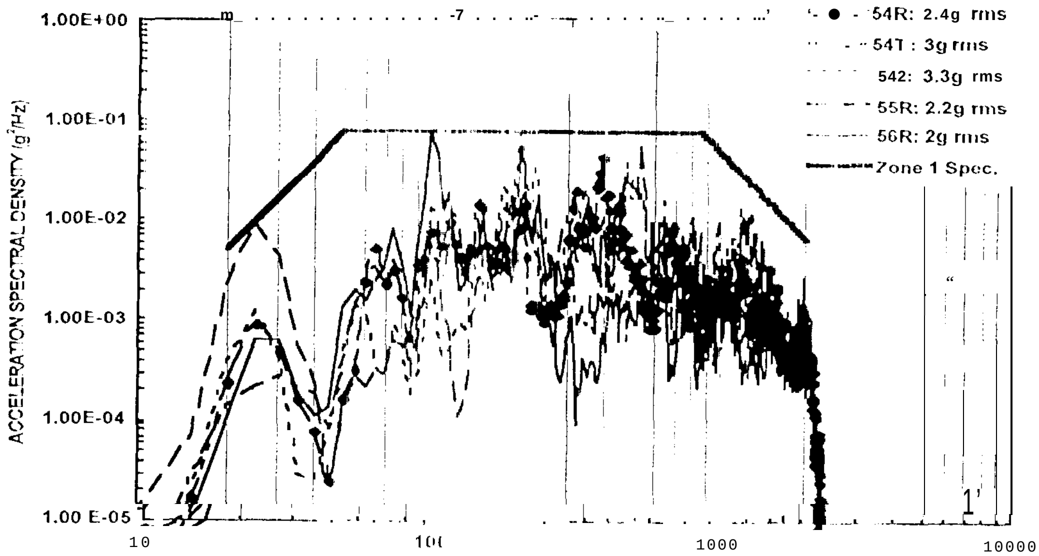


Fig. 5 Cassini RTG Base Force Data and Random Vibration Specification

5. RADIO PLASMA WAVE SUBSYSTEM ANTENNA ASSEMBLY (RPWS)

Figure 6 shows the engineering model of the Cassini RPWS mounted on a shaker for a lateral vibration test. Three small sized triaxial force gages are mounted between the rectangular test fixture and the RPWS triangular base. Figure 7 shows the acceleration data measured in different axes at the RPWS base during the Sept. 95 DTM acoustic test. Also shown in Fig. 7 is the RPWS random vibration test acceleration specification (0.15 G^2/Hz), which corresponds to Cassini equipment zone 2. Fig. 7 shows that the data exceed the specification by 7 dB at 55 Hz for the z axis (normal) and " are about 4 dB below the



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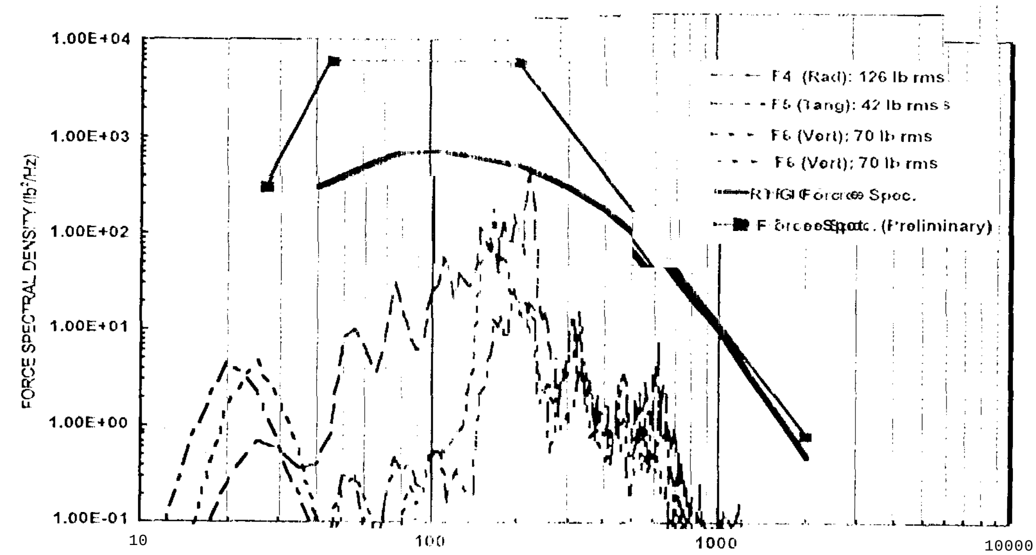

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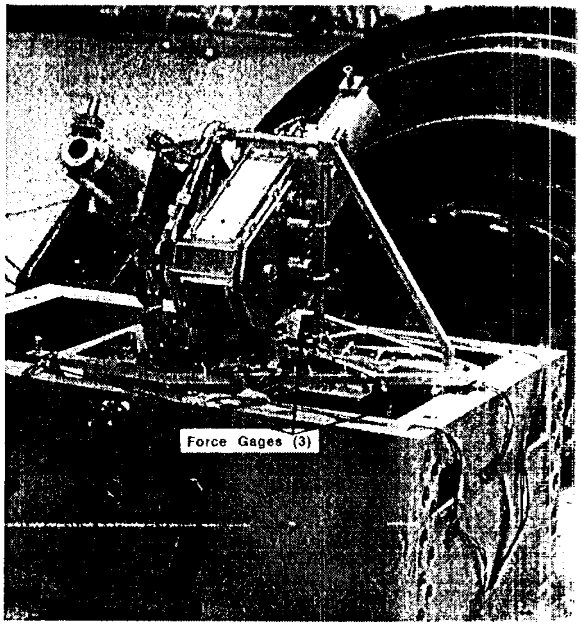

Fig. 6 Engineering Model of Cassini RPWS Mounted for Lateral Vibration Test

Figure 8 shows the 1'()]CC data measured in different axes at the RPWS base during the Sept. 95 DTM acoustic test together with the RPWS random vibration test force specification. The force specification is 8 dB greater than the data at 55 Hz and much greater at high frequencies. Also shown is the Cassini generic preliminary force specification which is very conservative.

6. PROPULSION MODULE SUBSYSTEM ELECTRONIC ASSEMBLY (PMSEA)

Figure 9 shows the flight Cassini PMSEA mounted on a shaker for the axial vibration test. Four small sized triaxial force gages are located at the corners of the PMSEA base, between the shaker head expander and the base. Here, as with the RTG and RPWS items, no additional fixturing was necessary to install the force gages in the spacecraft DTM acoustic test or in the equipment vibration tests. The flight fasteners were simply made longer to accommodate the force gage thickness.

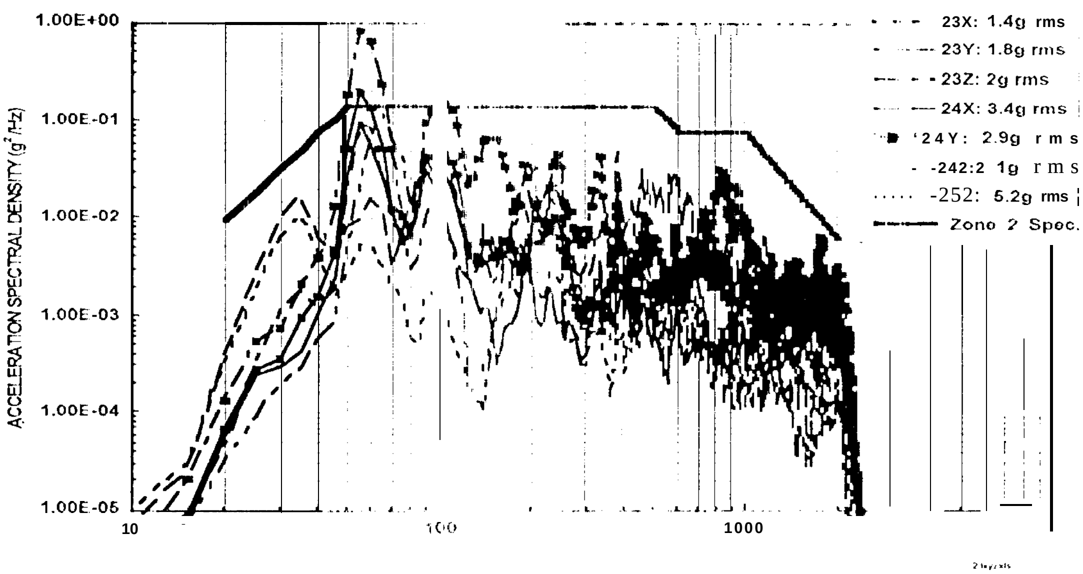

Fig. 7 Cassini RPWS Base Acceleration Data and Random Vibration Specification

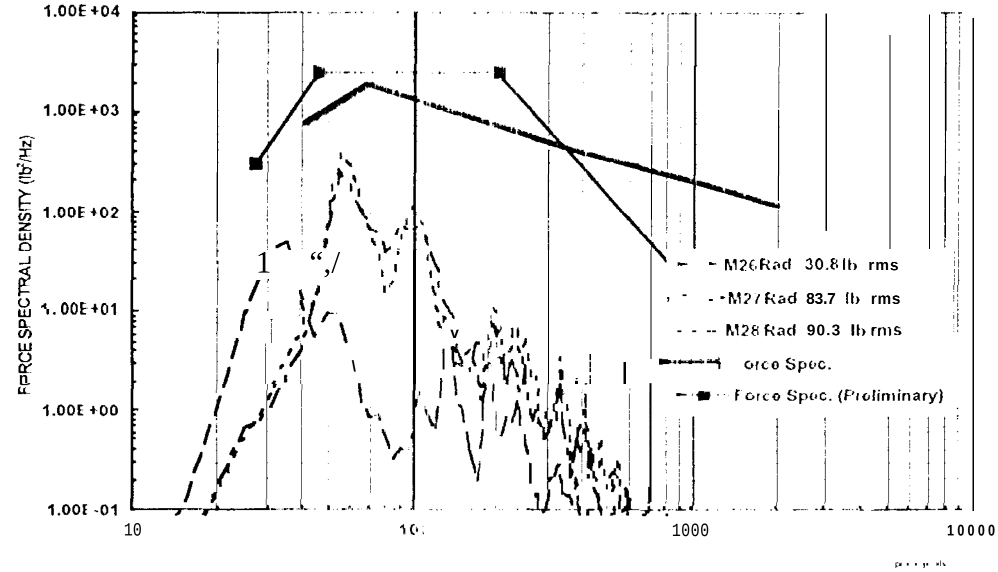

Fig. 8 Cassini RPWS Base Force Data and Random Vibration Specification

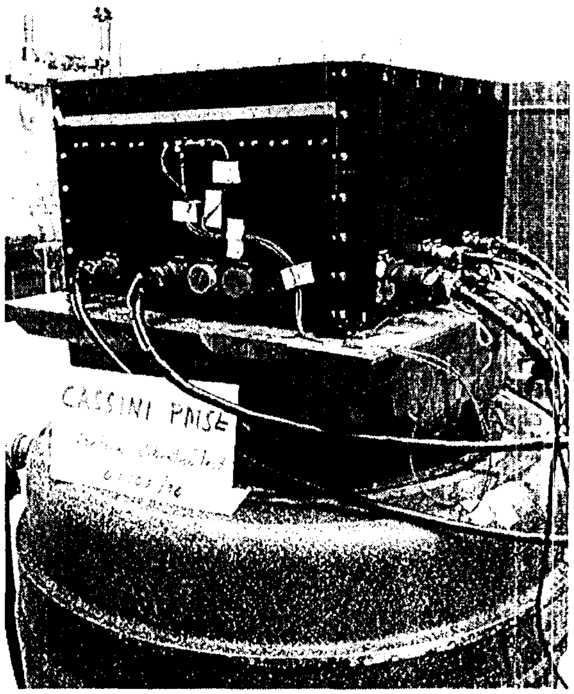

Fig. 9 Cassini Flight PMSEA Mounted for Axial Vibration Test

Figure 10 shows the acceleration data measured in different axes at the PMSEA base during the Dec. 95 follow-on DTM acoustic test. (The PMSEA was simulated by a mass simulator in the Sept. 95 DTM acoustic test.) The PMSEA is a big electronic box mounted to the propulsion module section of the spacecraft (Fig. 1). Also shown in Fig. 10 is the PMSEA random vibration test acceleration specification (0.1 G^2/Hz), which corresponds to Cassini zone 3. The data are considerably less than the specification at the low frequencies but agree well at the higher frequencies, above 300 Hz. This behavior contrasts sharply with the strong fundamental-frequency response of the RPWS discussed previously. The strong high frequency response at the PMSEA interface is apparently not due to direct acoustic excitation, because the response was similar in the Sept. 95 DTM test when the PMSEA was modeled with a mass simulator.

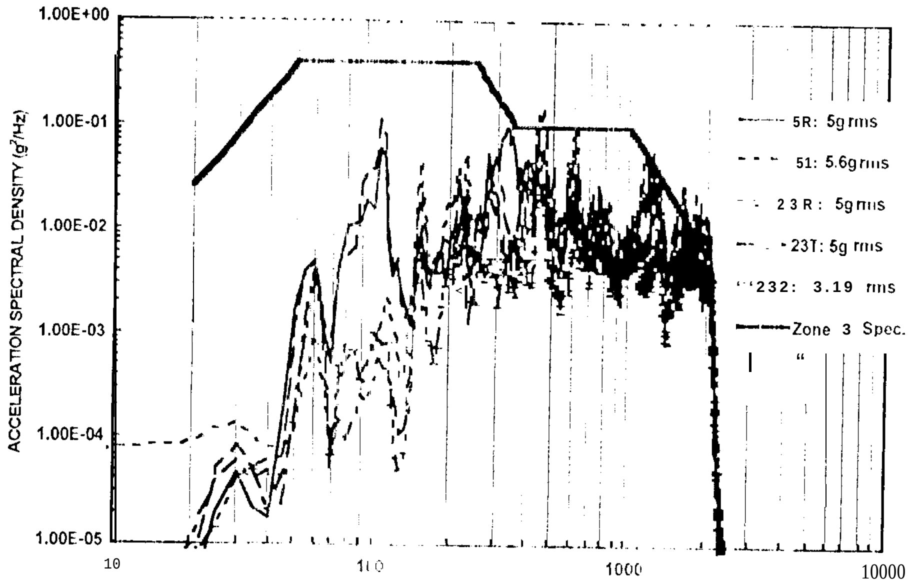

Fig. 10 Cassini PMSEA Base Acceleration Data and Random Vibration Specification

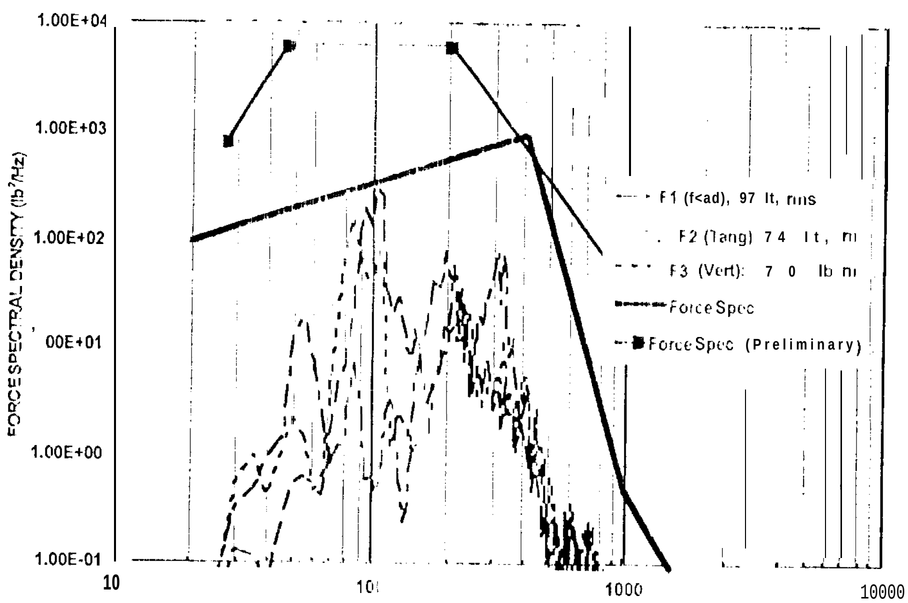

Fig. 11 Cassini PMSEA Base Force Data and Random Vibration Specification

Figure 11 shows the force data measured in different axes at the PMSEA base during the Dec. 95 follow-on DTM acoustic test together with the PMSEA force specification, which was actually derived by enveloping these data. (The random vibration test of the PMSEA occurred somewhat after the Dec. 95 DTM acoustic test, so that in this case it was possible to use the envelope of the acoustic test data as the force specification, rather than deriving the force specification from the TDFS analytical model.) Also shown is the Cassini generic force specification which is very much greater than the data.